ROBUST GPS KINEMATIC POSITIONING FOR DIRECT GEOREFERENCING

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ABSTRACT

The photogrammetric community is quickly accepting the new developments in GPS/INS integration, and direct georeferencing is becoming a widely applied technique.
However, as this technique has no (or very little) external control, the robustness of kinematic GPS positioning becomes a critical issue. In the paper, a technique for determining the GPS trajectory taking advantage of the regional GPS networks is presented as a way to increase the reliability of GPS derived trajectory and consequently of direct georeferencing.
The increasing number of regional permanent GPS networks allows for a differential kinematic positioning where instead of using a single GPS receiver as reference station, the whole set of receivers is used as a reference network for kinematic positioning. The permanent GPS network is used to generate small scale atmospheric models and to minimize orbital and multipath errors.
The geometrical constraints of the GPS network increase the robustness of the solution and increases the de-correlation between the ambiguity parameters and the atmospheric parameters helping to achieve correct ambiguity determination.

1 INTRODUCTION

Direct georeferencing is becoming an accepted technique among the photogrammetric community, where it is starting to compete with aerial triangulation for orienting frame images, (5), (4). In the field of linear sensors, where a different set of exterior orientation parameters has to be determined for each line, direct georeferencing is the most practical procedure for orienting the images.

Indirect methods (aerial triangulation) have redundant observations that make the block very robust (1). However, if direct orientation methods are used there is very little redundancy on the determination of the orientations, especially if the minimal hardware configuration is used (one Inertial Measurement Unit (IMU), one on-board GPS and one reference station). This paper studies the reliability of the GPS trajectory when a network of GPS reference stations is used instead of a single reference receiver.

2 NETWORK APPROACH

The number of permanent GPS stations has been growing in the past years. These networks have been seldom used for kinematic positioning; however, they represent a big potential for increasing the precision and robustness of kinematic surveying.

Providing that $\nabla\Delta\Phi_{1_{s_1,s_2}}^{rov,f_1}$ is a double difference phase observation between satellites s_1, s_2 and between the rover receiver (rov) and a fixed receiver (f_1), the original way of using a network of permanent GPS stations is by using all possible double difference observations between the rover receiver and all the permanent GPS stations:

$$\nabla\Delta\Phi_{1_{s_1,s_2}}^{rov,f_i} \quad with\ i = 1 \div n\ where\ n\ is\ the\ number\ of\ permanent\ stations \tag{1}$$

and by applying the appropriate covariance matrix.

This approach increases the number of observations used and helps to mitigate multipath errors affecting the observations from the reference stations. But in order to help the de-correlation of the different parameters that are computed (ambiguities, ionospheric delay, tropospheric delay, $\cdots$) it is possible to compute a priori these parameters within the network and use them as constraints in the kinematic trajectory computation. So, in case of a network of 3 receivers the double difference ambiguity, ionospheric parameters as well as the tropospheric parameters within the network will be computed

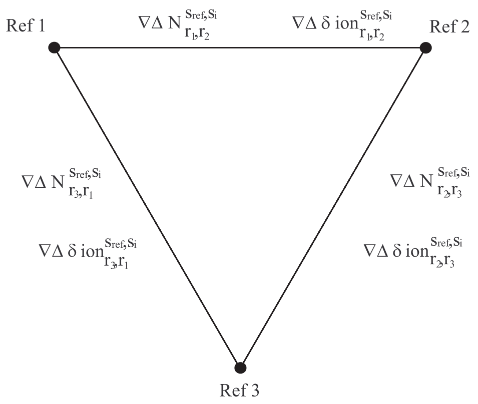

Figure 1: First step, computation of the network ambiguities

in a preliminary step (see 1). The computed parameters shown in figure 1 are not independent and the following relation must be verified.

$$-\nabla\Delta N^{s_{ref},s_i}_{r_3,r_1} \quad = \quad \nabla\Delta N^{s_{ref},s_i}_{r_1,r_2} + \nabla\Delta N^{s_{ref},s_i}_{r_2,r_3} \tag{2}$$

$$-\delta ion^{s_{ref},s_i}_{r_3,r_1} \quad = \quad \delta ion^{s_{ref},s_i}_{r_1,r_2} + \delta ion^{s_{ref},s_i}_{r_2,r_3} \tag{3}$$

Solving ambiguities within the network is much easier than in a kinematic survey, because the receiver is stationary and the coordinates of the permanent GPS stations are known very precisely. In a second step the kinematic trajectory is computed using all the possible double difference observations between the rover receiver and every reference station, as shown in figure 2. As mentioned before, the correlation between the double difference observations formed from different reference stations has to be taken into account.

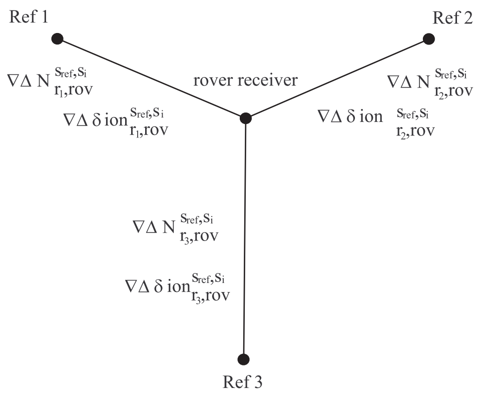

Figure 2: Second step, applying network constraints

On the trajectory computation the results of step 1 are used as constraints for helping parameter de-correlation and for increasing robustness. So, following the notation of 1 and 2 the following constraints will be applied:

$$\nabla\Delta N^{s_{ref},s_i}_{r_i,r_j} \quad = \quad \nabla\Delta N^{s_{ref},s_i}_{r_i,rov} - \nabla\Delta N^{s_{ref},s_i}_{r_j,rov} \tag{4}$$

$$\delta ion^{s_{ref},s_i}_{r_i,r_j} \quad = \quad \delta ion^{s_{ref},s_i}_{r_i,rov} - \delta ion^{s_{ref},s_i}_{r_j,rov} \tag{5}$$

In case of observing m satellites with n dual frequency reference receivers there will be 2·(m-1)·n double difference ambiguity parameters, but only 2·(m-1) parameters (corresponding to one reference station) have to be solved because the constraints applied will propagate the ambiguities to the remaining reference stations.

2.1 Ionospheric Models

One of the main problems when computing medium-long range kinematic positioning is the ionospheric delay. Differential ionospheric delay is the main cause for not being able to solve ambiguities at distances greater than 20 km from the reference station. However, when kinematic surveying is done within the area covered by a network of permanent GPS stations, it is possible to build a local/regional ionospheric model covering that area.

The use of ionospheric models has a much bigger influence on the de-correlation of ambiguities and atmospheric parameters than if the constraints from equation 5 are applied to double difference ionospheric delays. An ionospheric model based on a tomographic approach based on a network of reference stations is explained in (3), and was tested successfully in (2).

3 EMPIRICAL STUDY OF RELIABILITY

Although the precision of a GPS derived trajectory is a very important parameter, it has to be kept in mind that if there are any systematic errors in the survey (i.e. undetected cycle slip), the a posteriori covariance matrix of the trajectory no longer represents an acceptable measurement of the quality of the survey (8). This is why the survey's ability to check the presence of modeling errors (usually cycle slips in GPS surveys) also has to be studied. This ability is called the reliability of the survey.

Instead of the internal reliability of a survey (capacity of the survey to detect blunders), the Minimal Detectable Bias (MDB) is usually computed, so a bias on one observation with a magnitude smaller than the corresponding MDB will not be detected in the hypothesis test, given a certain level of significance and power, (7). The influence of a bias with a magnitude equal to the MDB in the computed parameters is called the external reliability. A good internal reliability does not always imply an acceptable influence on the position computation.

A real photogrammetric flight was used to test the influence of using a network of permanent GPS stations on the internal and external reliability of the survey. Figure 3 shows the flight path and the GPS permanent stations that surrounded the area. That flight had a poor satellite geometry; however, under production environment it is not always possible to select an optimal satellite window.

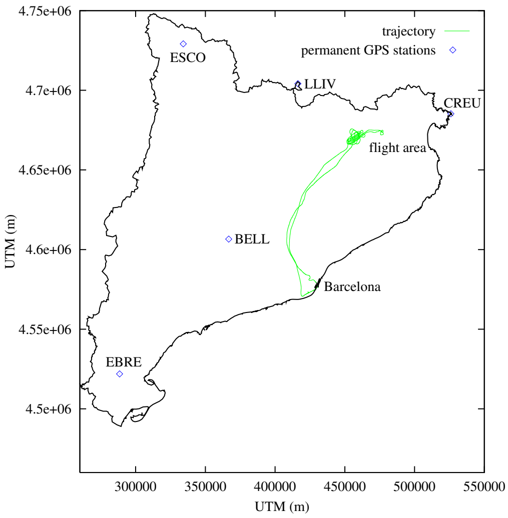

Figure 3: Flight test

If there is an undetected cycle slip (bias) on the data collected by the reference station the gain when processing the flight using a network of GPS stations is clear, the observations from the rest of reference receivers will be used for identifying and correcting the cycle slip.

In a kinematic survey it is more probable to have an undetected cycle slip (bias) on the moving receiver. The MDB on a L1 phase observation recorded by the kinematic receiver has been computed on the test flight. In figure 4 the MDB of one satellite is plotted for both cases, using a single reference station and using a network of reference stations. The improvement is very significant especially if one considers that a cycle slip of one cycle in L1 phase corresponds to a 0.19 m bias. The corresponding external reliability (effect on position) can be seen in figure 5.

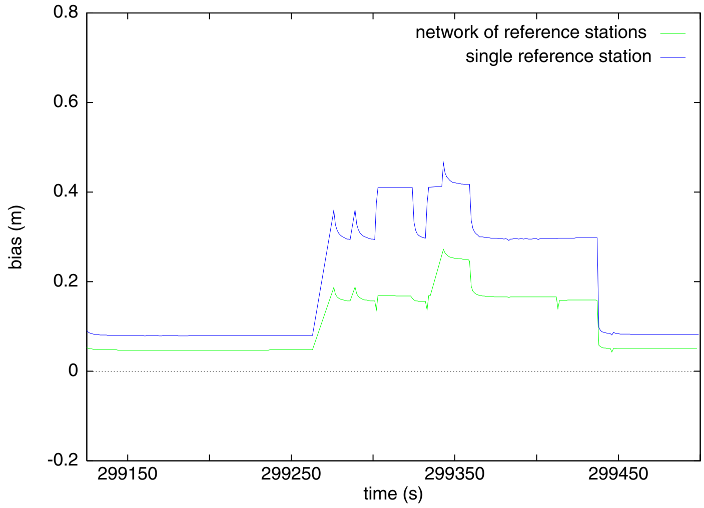

Figure 4: MDB on the kinematic receiver, L1 observation (Internal reliability)

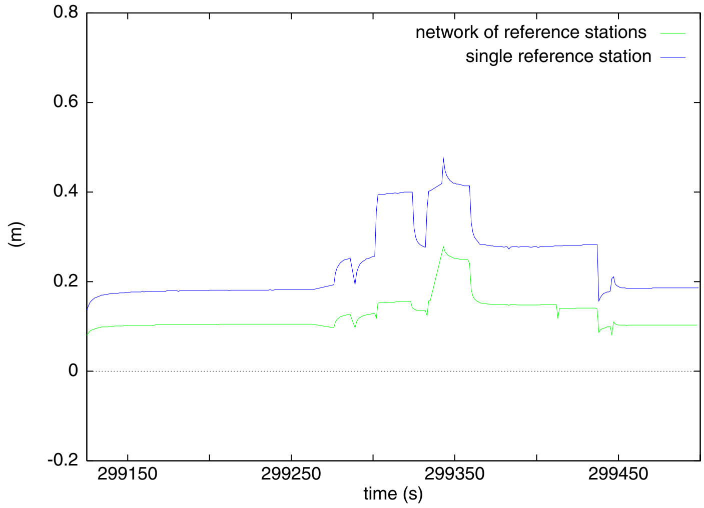

Figure 5: External reliability (Bias on the kinematic receiver, L1 observation)

Detection of L1 bias on a kinematic receiver can also be done by comparison with the corresponding L2 observation. However, the detection of a simultaneous cycle slip on L1 and L2 phase observations is one of the most difficult biases to detect. The improvement in the detection of such bias when using a network of permanent receivers can be seen in figure 6. The effect on the computation of the trajectory of an undetected bias is shown in figure 7.

4 USE OF EXISTING PERMANENT NETWORKS

In an airborne survey the GPS receiver should record data as often as possible because in high dynamics environments the interpolation of the trajectory can lead to a non-negligible error source. For instance, the kinematic positions of an on-board receiver of a standard surveying airplane flying at 200 knots and recording data at 1Hz will be spaced about 100 m. Also, its velocity can vary more than 2 m/s from one epoch to the following. One of the main problems of using existing GPS permanent networks is that the recording rate of the GPS permanent receiver can be lower (1/5 – 1/30 Hz) than the recording rate of an airborne GPS receiver ($>$ 1 Hz). The question that arises is whether it is possible to use the observations of those reference stations.

The GPS data recorded by the kinematic receiver contain information about the dynamics of the GPS antenna and are affected by ephemeris, ionospheric, tropospheric, satellite and receiver clock errors, while the data from a GPS reference

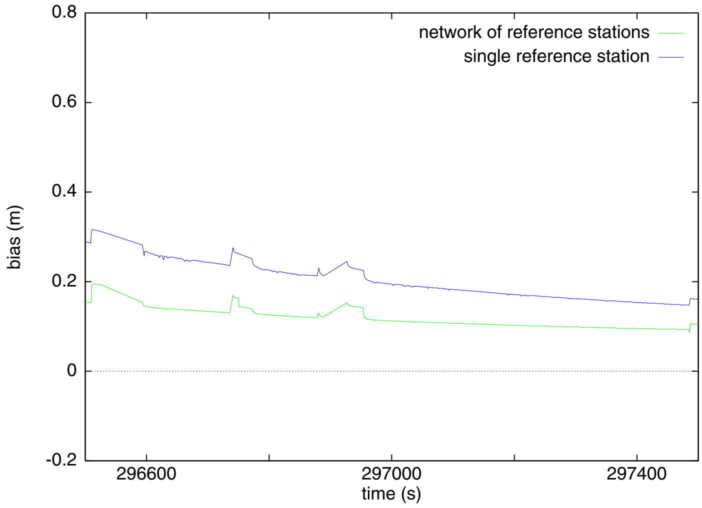

Figure 6: MDB on the kinematic receiver, L1 & L2 observations (Internal reliability)

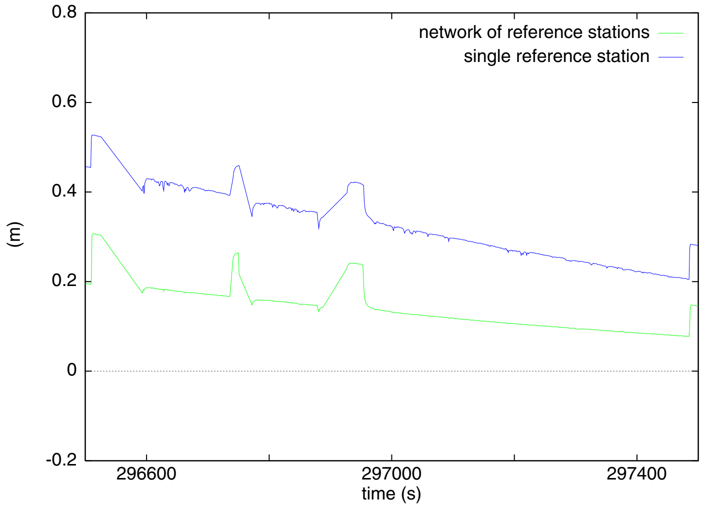

Figure 7: External reliability (Bias on the kinematic receiver, L1 & L2 observations)

station are located at a known position and are also affected by ephemeris, ionospheric, tropospheric, satellite and receiver clock errors with a very high correlation with the errors from the kinematic receiver. Double difference GPS positioning cancels/mitigates common errors and allows for the determination of the kinematic GPS trajectory.

So, in principle, the dynamic of the kinematic receiver has to be the decision factor for choosing the recording rate of the kinematic receiver, and the dynamics of the errors that affect both reference and rover receiver has to be the decision factor for choosing the recording rate at the reference station.

If the dynamic of the common errors is studied, it can be seen that the atmospheric and ephemeris errors have a very slow dynamic (apart from ionospheric scintillation effects); the satellite clock error can have a higher dynamic (due to SA) but even in these cases it is possible to interpolate the error for a few seconds. In (6) an empirical study was conducted to learn the error in kinematic positioning when using one reference station recording data at a frequency lower than 1 Hz and a rover receiver recording at 1Hz. The results are summarized in table 1.

This situation can be even better if the Selective Availability is switched off as expected in the near future; then, the dynamic of the satellite clocks will be much more predictable.

Another possibility is to have one reference station recording data at 1Hz and the rest of the network recording data at a lower recording rate. In this way the trajectory can be computed using all the data available, the satellite clock errors can be corrected using data from the reference station recording at 1 Hz, and the ephemeris and atmospheric errors can be corrected using the whole network of receivers.

		recording rate at reference station					
		5 s	10 s	15 s	20 s	25 s	30 s
flight 1	horizontal	0.002	0.004	0.011	0.023	0.032	0.060
	vertical	0.002	0.011	0.026	0.055	0.081	0.142
flight 2	horizontal	0.003	0.006	0.012	0.024	0.039	0.055
	vertical	0.010	0.019	0.033	0.060	0.092	0.149

Table 1: Error of the kinematic trajectory (RMS) units in m.

5 CONCLUSIONS

Direct georeferencing is becoming very popular for orienting airborne sensors. However, the reliability of direct methods is still an important issue that has to be addressed. Also, in very demanding applications such as large scale photogrammetric flights or laser scanning, the precision of GPS positioning is a limiting factor.

The paper has shown how the use of a network of GPS permanent stations can help to improve the reliability of the survey, making the GPS derived trajectory more robust and precise. The number of GPS permanent stations is growing continuously, and several national networks are being deployed around the world. These infrastructures should be taken into account for improving kinematic positioning and making direct georeferencing more reliable.

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